Clinical Neurophysiology xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Heart rate variability evaluation of Emfit sleep mattress breathing categories in NREM sleep

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A R T I C L E I N F O

Article history:
Accepted 20 August 2014
Available online xxxx

Keywords:
Sleep mattress sensors
Emfit sensor
Heart rate variability
Sleep
Flow limitation
Sleep-disordered breathing

H I G H L I G H T S

- The periodic obstructive breathing detected by the Emfit mattress induces similar effects on autonomous nervous system as sleep apnea.
- Instead, during the sustained partial obstruction sympathetic activity did not increase but parasympathetic activity increased.
- Sustained partial obstruction seems to be a distinct entity differing from sleep apnea.

A B S T R A C T

Objective: Heart rate variability (HRV) analysis of obstructive sleep apnea patients reveals an increase in sympathetic activity. Sleep disordered breathing (SDB) can be also assessed with sleep mattress sensors, as the Emfit sensor, by dividing the signal into different breathing categories. In addition to normal breathing (NB) and periodic apneas/hypopneas (POB), the sleep mattress unveils a breathing category consisting of sustained partial obstruction (increased respiratory resistance, IRR). The aim of our study was to evaluate HRV during these three breathing categories in NREM sleep.
Methods: 53 patients with suspected SDB underwent an overnight polysomnography with an Emfit mattress. The Emfit signal was scored in 3-min epochs according to the established rules. The NB, POB, and IRR epochs were combined to as long NB, POB and IRR periods as possible and HRV was calculated from at least 6-min epochs.
Results: The meanHR did not differ between the breathing categories. HRV parameters revealed an increase in sympathetic activity during POB. The mean LF/HF ratio was highest during POB (3.0) and lowest during IRR (1.3). During NB it was 1.7 (all p-values $\leqslant 0.001$). Interestingly sympathetic activity decreased and parasympathetic activity increased during IRR as compared to NB (the mean HF power was 1113.8 ms^2 during IRR and 928.4 ms^2 during NB).
Conclusions: The HRV findings during POB resembled HRV results of sleep apnea patients but during sustained prolonged partial obstruction a shift towards parasympathetic activity was achieved.
Significance: The findings encourage the use of sleep mattresses in SDB diagnostics. In addition the findings suggest that sustained partial obstruction represents its own SDB entity.

1. Introduction

Obstructive sleep apnea (OSA) constitutes a risk factor for cardiovascular diseases (Kohler and Stradling, 2010). OSA with

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http://dx.doi.org/10.1016/j.clinph.2014.08.012
1388-2457/

Please cite this article in press as: Tenhunen M et al. Heart rate variability evaluation of Emfit sleep mattress breathing categories in NREM sleep. Clin Neurophysiol (2014), http://dx.doi.org/10.1016/j.clinph.2014.08.012

repetitive apneas increases sympathetic tone (Somers et al., 1995) which may be one of the main predisposing factors for cardiovascular morbidity. The effect of OSA on the autonomous nervous system can be studied with heart rate variability (HRV) analysis (Stein and Pu, 2012).

Sleep mattress sensors provide a non-invasive means to evaluate nocturnal breathing. The SCSB (Static Charge Sensitive Bed) or Emfit mattress (Fig. 1) signal is usually scored into different breathing categories in 3-min epochs. They both are proven to be suitable for apnea detection (Polo, 1992; Tenhunen et al., 2011, 2013). In addition, the SCSB and Emfit recordings of sleep-disordered breathing (SDB) patients often present with an increased respiratory resistance-pattern (IRR). IRR is considered to represent sustained partial obstruction, which can be assessed, for example, by oesophageal pressure measurement where sustained negative increase can be seen, and by flow limitation pattern in nasal pressure recordings (Polo, 1992; Bao and Guilleminault, 2004; Tenhunen et al., 2011). IRR is frequent among postmenopausal women, patients with IRR are as sleepy as OSA patients, and there seems to be a relation between IRR and mood disorders (Polo-Kantola et al., 2003; Tenhunen et al., 2013). However, more detailed characterization of IRR is still incomplete.

In the present study we evaluated the differences between HRV parameters in three different Emfit breathing categories: normal breathing, (NB), periodic obstructive breathing (POB, representing apneas and hypopneas), and during IRR (representing sustained partial obstruction). Examples of the breathing categories are presented in Fig. 2. The HRV evaluation of the sleep mattress breathing categories has not been performed before. We aim to find out if HRV results during POB resemble HRV findings during OSA. Since there are observations suggesting that IRR represents its own SDB entity, different from OSA, the other aim is to deepen the knowledge of IRR by comparing the HRV findings between IRR and POB. To our best knowledge, the HRV analysis during sustained partial obstruction has not been performed earlier.

2. Methods

2.1. Subjects and recordings

Fifty-three subjects (37 male, 16 female), referred to the Sleep Laboratory of Pirkanmaa Hospital District, volunteered to participate in the study. The patients were referred because of suspected

Fig. 1. Photograph of the Emfit mattress and the Static Charge Sensitive Bed (SCSB). In the figure the smaller, rectangular Emfit mattress is placed on the full bed sized SCSB for comparison. During the night the Emfit mattress is covered with an ordinary foam mattress and sheet.

SDB. The exclusion criteria were: cardiac arrhythmias, pacemaker or ischemia, cardiomyopathy, history of neurological or pulmonological diseases, diabetes, and drugs known to impair the function of autonomic nervous system. The Ethical Committee of the Pirkanmaa Hospital District approved the study and all the patients gave their written informed consent.

Sleep recordings were performed in the sleep laboratory with the Embla N7000 device (Embla®, Natus Medical Inc., USA) and the Somnologica Studio software (Medcare®, Iceland). The recordings consisted of eight EEG derivations (Fp1-M2, Fp2-M1, F3-M2, F4-M1, C3-M2, C4-M1, O1-M2, O2-M1), two EOG channels, three electromyogram channels (chin and both legs), airflow with a thermistor and a nasal pressure transducer, thoracic and abdominal respiratory movements, pulse and oxygen saturation by an integrated oximeter (Nonin Medical Inc., USA) a position and an electrocardiogram (ECG, leads between the lower left rib cage and the right clavicula notch). Oesophageal pressure (pESO) was measured with a separate manometry device (Reggie, Camtech AS, Norway). The position of the multichannel oesophageal catheter was fixed so that the pressure sensor was 16 cm from the posterior border of the soft palate. In addition, the Emfit mattress (32 cm × 62 × 0.4 cm, Emfit Ltd, Finland), was placed under a normal foam mattress and under the thoracic area of the sleeping subject. The unfiltered Emfit signal was acquired directly as a separate trace in the Somnologica software. A sampling rate of 2 Hz was used for the pulse oximeter (SpO_2 and pulse rate), 10 Hz for respiratory movements, 500 Hz for ECG, and 200 Hz for all the other signals.

2.2. Visual scoring

Polysomnographies were classified into sleep stages according to standard criteria (Iber et al., 2007). AHI was calculated as the number of obstructive apneas and hypopneas per hour of sleep. Obstructive apnea was defined as a decrease of at least 90% in the thermal signal lasting for at least 10 s. Hypopnea was scored from the nasal pressure signal when the amplitude drop was 50% or more and the event was associated with desaturation (≥3%) or an arousal, hypopnea rule 4 B (Iber et al., 2007). Arousals were scored according to the criteria of the American Sleep Disorders Association (ASDA, 1992).

The raw Emfit mattress signal detects large body movements. By means of signal processing, respiratory movements and short, spiky movements related to heart activity and respiratory effort can be extracted. The respiratory effort spikes have been found to correlate with increased negative intrathoracic pressure (Tenhunen et al., 2011). During apneas and hypopneas these high-frequency spikes show periodic patterns (waxing and waning or present–absent) but during sustained partial upper airway obstruction the spikes are more continuous (Fig. 2). With the raw and the filtered channels, the Emfit signal was visually scored in 3-min epochs into different breathing categories as described earlier, but according to our latest results the three different obstructive periodic breathing categories were combined to form the periodic obstructive category (POB) (Tenhunen et al., 2013). Scoring was performed during sleep stages only and epochs with wakefulness, movements and artefacts were omitted. The breathing categories used were normal breathing (NB), periodic breathing without increased respiratory effort (P1), periodic obstructive breathing (POB), periodic central breathing and increased respiratory resistance (IRR). The Emfit signal was scored visually from a lights off-event to the final awakening by two independent scorers with a scoring agreement of 85.0% (median, range 69.9–95.7%). The median Kappa value was 0.78 (0.41–0.93), indicating substantial agreement (Landis and Koch, 1977). The consensus scoring, which was used in the analyses was formed by two independent scorers

(a)

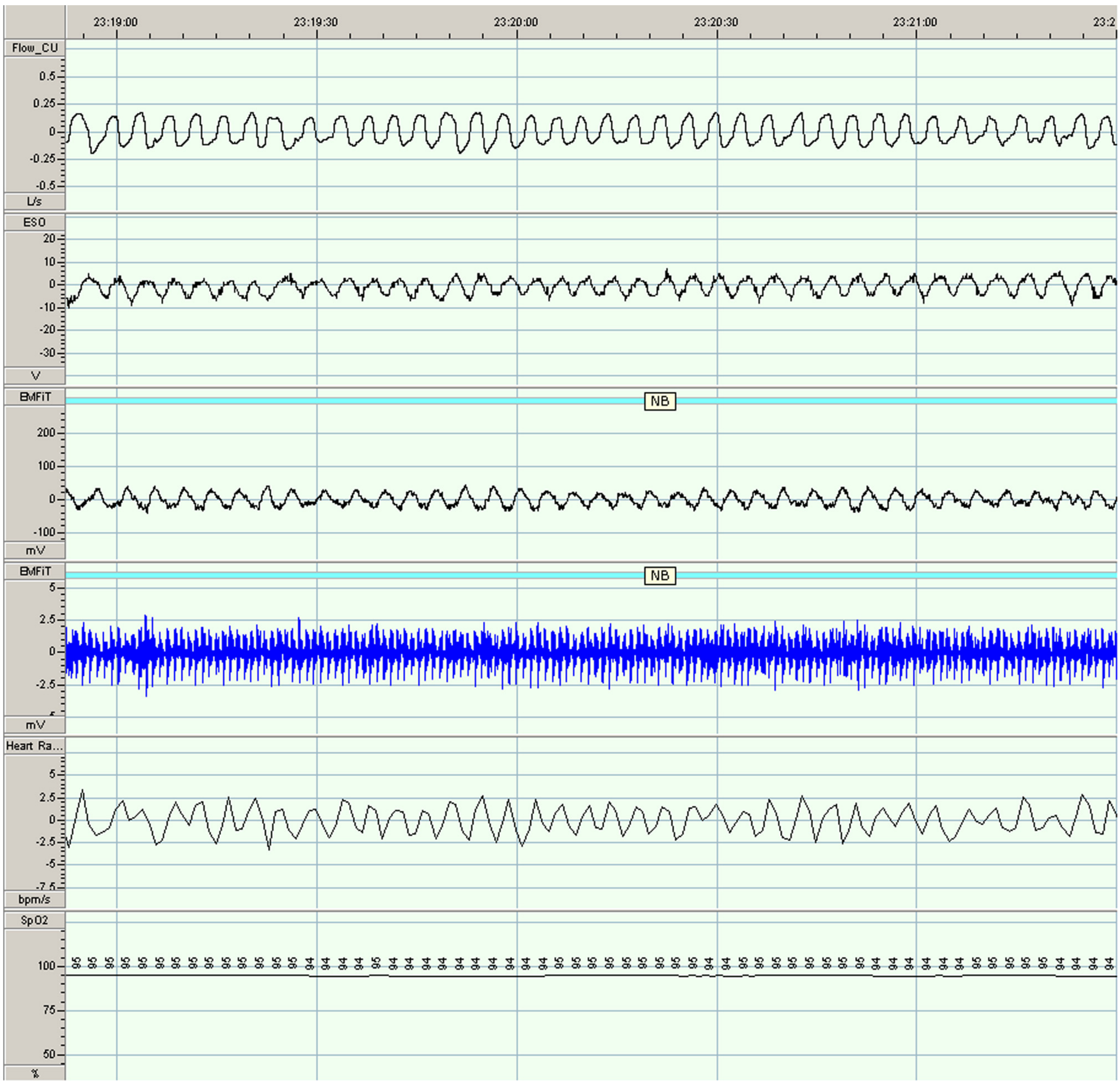

Fig. 2. Examples of 3-min epochs of different breathing categories. Traces from top to bottom: nasal flow, oesophageal pressure, respiratory movements by Emfit mattress, high frequency trace of Emfit, heart rate variation, oxygen saturation. The figures are from the same male subject suffering from sleep apnea and sustained partial obstruction. The scale of the traces is equal in all. (a) Normal breathing (NB) with regular respiration, no respiratory events, normal intrathoracal pressure, no high frequency spikes, moderate heart rate variation, no desaturations. (b) Periodic obstructive breathing (POB) with obstructive apneas, oesophageal pressure swings, periodic breathing with periodic high frequency spikes on Emfit traces, clear heart variation and desaturations. (c) Increased respiratory resistance (IRR) with regular breathing, increased negative intrathoracal pressure, regular breathing with continuous high frequency spikes on Emfit traces, moderate heart rate variation, no desaturations.

together. During the consensus scoring procedure the sustained intrathoracic negativity of IRR-epochs and the negative pressure swings during POB periods were confirmed visually from the pESO-signal. IRR was not found during REM sleep. As HRV during NREM differs from REM sleep, we decided to concentrate on NREM sleep only, since one of the aims was to evaluate the HRV differences between the POB and the IRR periods.

2.3. HRV analysis

The mean HRV parameters of all at least 6-min periods of NB, POB and IRR were calculated and then averaged. The HRV analyses were carried out using Kubios HRV analysis software (Tarvainen et al., 2014). First the QRS complexes were detected from the ECG signal by an adaptive QRS detection algorithm, RR-interval time series were formatted and erratic heart beats and artefacts were omitted. Before spectrum estimation, the HRV time series were interpolated using a 4 Hz cubic spline interpolation in order to have equidistantly sampled time series. The trend of HRV time series was removed using smoothness priors method with cut-off frequency 0.001 Hz (Tarvainen et al., 2002). Time domain measures of HRV were estimated from the 5-min segments of the HRV time series. From these epochs mean heart rate (meanHR), standard deviation and minimum and maximum of normal-to-normal RR intervals (SDNN, RRmin, RRmax) were calculated. Parameter series formed from 5-min intervals allows tracking parameter changes during the whole night. The spectrum of heart rate variability was analyzed in three frequency bands: a very low

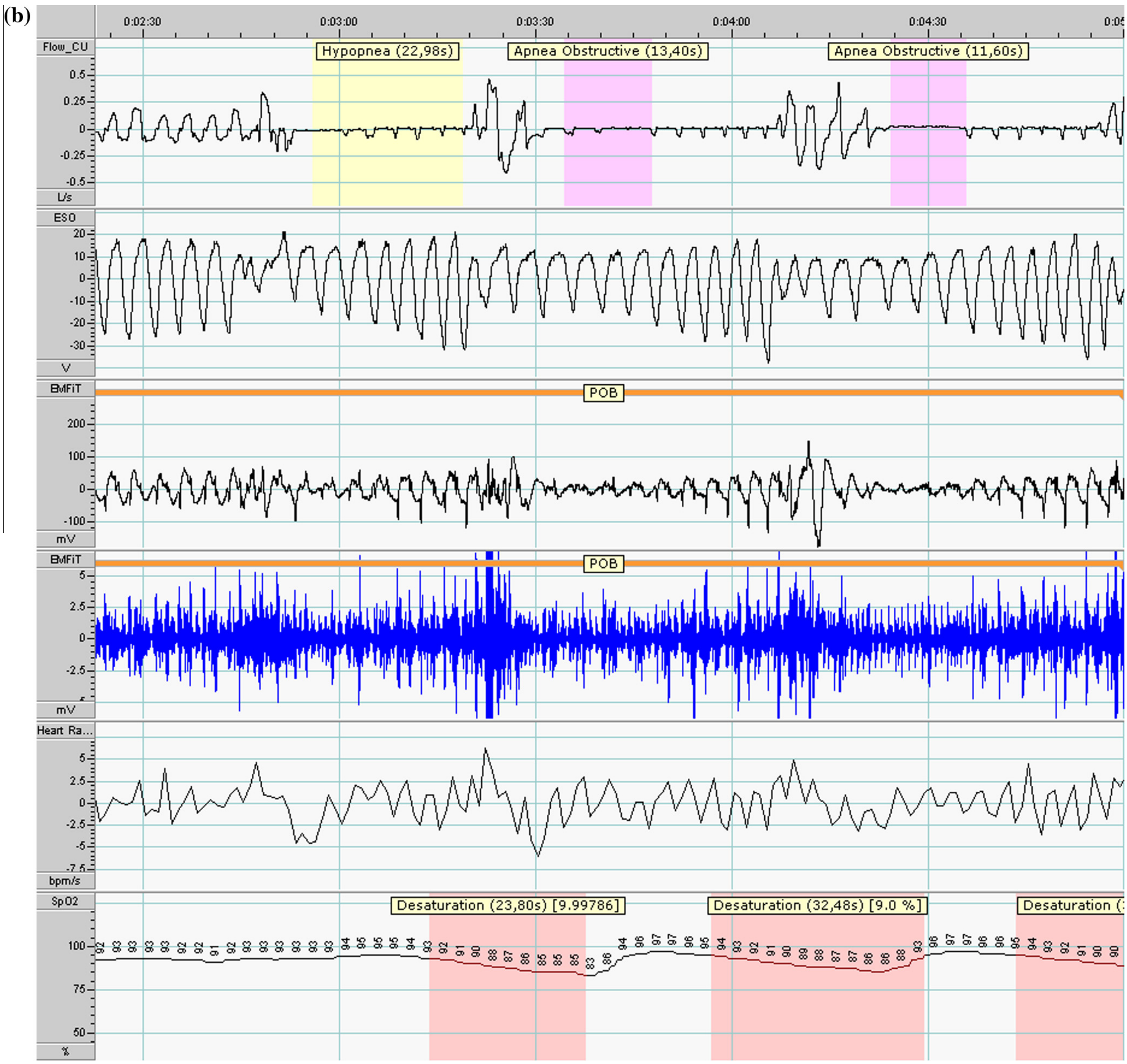

Fig. 2 (*continued*)

frequency band (VLF, 0.003–0.04 Hz), a low frequency band (LF, 0.04–0.15 Hz) and a high frequency band (HF, 0.15–0.4 Hz). In addition, the LF/HF-ratio was calculated (American Heart Association, 1996). VLF power is considered to reflect vagal and renin–angiotensin system effects on heart rate, LF reflects both sympathetic and parasympathetic effects, whereas HF reflects parasympathetic activity.

2.4. Statistics

Statistical analyses were performed with the IBM® SPSS® Statistics version 20 (IBM corp.). Non-parametric tests were used as all the variables were not normally distributed. The Friedman test was used to estimate if dependent variables vary by Emfit breathing category. The Wilcoxon signed-rank test with Bonferroni corrections (factor 3) was used in post hoc analyses. The probability level of 5% was considered as significant in the statistical tests.

3. Results

3.1. Demographic and sleep profile data

The median age of the patients was 45 years (range 25–68 years). The body mass index (BMI) ranged from 20.1 to 53.9 kg/m^2, with a median of 29.7 kg/m^2. Forty-four out of the 55 patients had OSA (AHI > 5/h). Fifty-one patients had at least one 3-min POB-epoch, 47 patients had at least one IRR-epoch and 51 had one or more NB-epochs. The sleep parameters of the patients are presented in Table 1.

3.2. HRV analyses

The time domain results are presented in Table 2. The comparisons between the meanRR intervals (or meanHR) did not yield significant differences between the three breathing

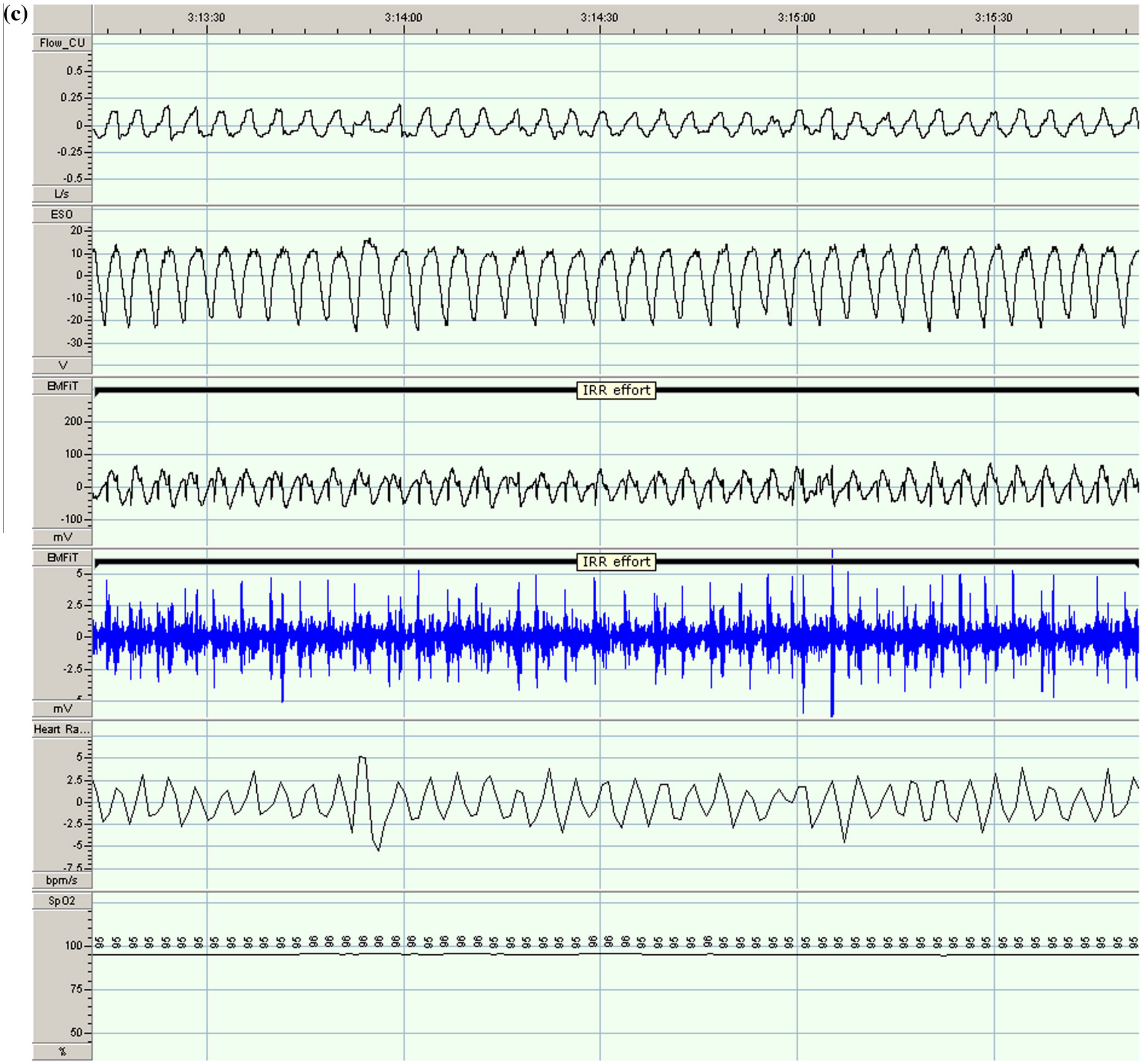

Fig. 2 (*continued*)

categories. The minimum RR interval was shorter (and maximum HR higher) during POB than during NB and IRR. The maximum RR interval was shorter (minimum HR higher) during IRR than during NB and POB. The SDNN reflecting over HRV was higher during POB than during NB and IRR. The other comparisons did not show statistically significant differences.

The frequency domain results are presented in Table 3. The absolute total power, VLF-power and LF power were highest during POB while NB and IRR did not differ from each other. In the HF band the power was lowest during NB, POB and IRR did not differ. The LF/HF ratio was highest during POB and lowest during IRR.

4. Discussion

The sleep mattress sensors have been used in SDB diagnostics in Finland for decades (Polo, 1992). The mattress scoring is based on the different traces extracted from the signal: one trace reveals large body movements, the other respiratory movements, and the third channel shows high frequency spikes. Experimentally, in awake subjects, the spikes are found to be connected with increased respiratory effort (Kirjavainen et al., 1996). However, the validity of mattress outcomes concerning SDB diagnostics has not fully been appreciated. The mattress sensors provide easy and non-invasive means to detect SDB (Norman et al., 2014), and that is why we have been concentrating on re-evaluating the outcomes from different aspects using the Emfit mattress. According to our results, apneas, hypopneas and EEG-arousals are almost absent and the oesophageal pressure is in the normal range during NB (Tenhunen et al., 2011). During POB, apneas, hypopneas and EEG-arousals are abundant and oesophageal pressure shows negative swings. In addition, the AHI correlates highly with the percentage of time spent in POB (Tenhunen et al., 2013). During IRR, apneas, hypopneas and EEG-arousals do not exist, but the negative oesophageal pressure is increased during inspirations for long periods.

The effects of the Emfit breathing categories on the autonomous nervous system have not been evaluated before. The NB category consists mostly of round flow shapes in the nasal pressure signal,

Table 1
Sleep parameters of the 53 patients.

	Median	Min	Max	Mean	SD
TIB[a] (min)	493.0	349.5	644.0	490.8	64.9
TST[b] (min)	407.5	220.5	588.5	404.9	76.3
SEI[c] (%)	85.9	47.8	97.1	82.1	10.8
SL[d] (min)	15.5	1.0	74.5	21.5	18.4
REMlat[e] (min)	138.0	44.0	466.5	162.8	86.2
%N1[f]	7.2	0.1	40.6	9.1	6.7
%N2[f]	65.5	41.3	86.8	65.5	9.2
%N3[f]	9.7	0.0	45.0	11.4	9.2
%REM[f]	15.0	0.0	24.1	14.0	6.3
ARI[g]	20.7	0.5	59.2	20.7	13.9
AHI[h]	11.0	1.5	88.0	19.8	19.5
ODI4[i]	4.0	0.1	63.0	11.9	15.3
SaO_2min[j] (%)	87.0	66.0	93.0	85.7	5.6
PLMI[k]	3.7	0.5	42.0	7.7	10.4
%NB[l]	32.1	0	74.6	32.3	22.9
%POB[l]	28.3	0	85.0	33.7	25.7
%IRR[l]	12.4	0	55.3	15.0	13.3

[a] Time in bed.
[b] Total sleep time.
[c] Sleep efficiency index = TST/TIB.
[d] Sleep latency.
[e] Latency to REM (rapid eye movement) sleep.
[f] Percentage of sleep stage (N1-REM) referred to TST.
[g] Arousal index, number of cortical arousals per hour of TST.
[h] Apnea–hypopnea index, apneas and hypopneas per hour of TST.
[i] Oxygen desaturation index, number of desaturations ⩾4% per hour of TST.
[j] Minimum of oxygen saturation.
[k] Periodic limb movement index.
[l] Percentage coverage of normal breathing (NB), periodic obstructive breathing (POB) and increased respiratory resistance (IRR) referred to TST.

with no apneas/hypopneas, arousals or desaturations (Tenhunen et al., 2011). The mean heart rate of the NB periods did not differ from the POB or the IRR, which might reflect the insensitivity of the meanHR to detect periodic changes in autonomous nervous system. During NB the LF and HF powers remained low.

Periodic breathing is present during POB (Tenhunen et al., 2011, 2013). In the present work, the HR varied substantially during POB. The total power, as well as VLF, LF and HF powers were high as compared to NB and the HF/LF ratio was clearly increased. These results indicate increased sympathetic activity and autonomic modulation during the POB.

The increase in the VLF band might stem from the periodic type of breathing, as VLF has been found to increase during apneas and Cheyne–Stokes respiration (Mortara et al., 1997). The physiological processes behind the increase in sympathetic activity may be many. For example, the repetitive increases in negative intrathoracic pressure during apneas induce increases in the left ventricular transmural pressure (Peters et al., 1988). This increases afterload reducing stroke volume, which may decrease cardiac output (Tolle et al., 1983). Simultaneously the venous return is enhanced (Morgan et al., 1966). The resulting leftward shift of the interventricular septum may diminish left ventricular filling (Shiomi et al., 1991) reducing stroke volume. The diminished stroke volume is supposed to decrease baroreceptor firing leading to sympathetic activation. However, the intrathoracic negativity via increased aortic transmural pressure may stretch the muscle wall of the aorta (Peters et al., 1988) increasing the firing of aortic baroreceptors. In that way, the intrathoracic negativity may induce both an increase and a decrease of the sympathetic activity.

Table 2
Time series measures of HRV.

	NB mean ± SEM	POB mean ± SEM	IRR mean ± SEM	NB vs POB	NB vs IRR	POB vs IRR
meanRR (ms)	1039.9 ± 22.2	1037.8 ± 22.3	1027.4 ± 22.6	ns	ns	ns
meanHR (bpm)	59.2 ± 1.4	59.4 ± 1.4	60.1 ± 1.3			
minRR (ms)	783.4 ± 15.7	731.6 ± 15.7	810.7 ± 11.8	$p < 0.001$	ns	$p < 0.001$
maxHR (bpm)	78.4 ± 1.7	84.1 ± 1.4	75.8 ± 1.6			
maxRR (ms)	1339.3 ± 35.4	1335.0 ± 30.4	1261.9 ± 33.6	ns	$p < 0.001$	$p < 0.001$
minHR (bpm)	46.6 ± 1.3	46.2 ± 1.1	49.5 ± 1.4			
SDNN (ms)	43.1 ± 3.1	59.7 ± 4.4	43.2 ± 3.3	$p < 0.001$	ns	$p < 0.001$

NB normal breathing, POB periodic obstructive breathing, IRR increased respiratory resistance.
meanRR, minRR, maxRR, SDNN = mean, minimum, maximum and standard deviation of normal-to-normal RR intervals.
meanHR, maxHR, minHR = mean, minimum and maximum of beat-to-beat heart rate values in beats per minute.
SEM = standard error of mean.
Bonferroni corrected post hoc p-values are presented.
ns, not significant.
The Friedman test p-values for meanRR, minRR, maxRR and SDNN were 0.27, <0.001, 0.01, and <0.001, respectively.

Table 3
Frequency domain measures of HRV.

	NB mean ± SEM	POB mean ± SEM	IRR mean ± SEM	POB vs NB	POB vs IRR	NB vs IRR
Total power (ms^2)	2877.0 ± 389.5	6789.9 ± 974.1	2481.3 ± 371.0	$p < 0.001$	$p < 0.001$	ns
VLF (ms^2)	1097.5 ± 104.4	3259.6 ± 426.8	905.4 ± 96.2	$p < 0.001$	$p < 0.001$	ns
LF (ms^2)	866.6 ± 159.9	2099.5 ± 439.6	679.7 ± 141.4	$p < 0.001$	$p < 0.001$	ns
HF (ms^2)	928.4 ± 206.3	1263.1 ± 252.1	1113.8 ± 265.5	$p = 0.001$	ns	$p = 0.02$
LF/HF	1.7 ± 0.2	3.0 ± 0.3	1.3 ± 0.1	$p < 0.001$	$p = 0.001$	$p < 0.001$

NB normal breathing, POB periodic obstructive breathing, IRR increased respiratory resistance.
VLF = very low frequency power, LF = low frequency power, HF = high frequency power.
SEM = standard error of mean.
Bonferroni corrected post hoc p-values are presented.
ns, not significant.
The Friedman test p-value was 0.019 for HF and <0.001 for total power, VLF, LF and LF/HF.

The other mechanisms affecting the autonomous nervous system during apneas are hypoxia and hypercapnia, which increase both blood pressure and heart rate (Somers et al., 1989; Foster et al., 2009). Recently the impact of hypoxia on the increase in sympathetic activity has been stressed (Palma et al., 2013). Also arousals increase sympathetic tone (Ringler et al., 1990). In addition, hypoxia associated with arousal can induce an additive increase in sympathetic activity (O'Donnell et al., 1996). Hypoxia diminishes the amount of nitric oxide derivatives as well (Foster et al., 2009), which may lead to impaired local vasodilatation of the arterioles. As a net effect, all the physiological mechanisms during obstructive apnea are known to induce an increase in sympathetic tone (Somers et al., 1995). This increase was observed in our HRV results as expected, suggesting that periodic breathing detected by Emfit induces similar physiological alterations to autonomous nervous system as OSA.

Conventionally sustained partial obstruction, lasting up to several minutes, can be assessed either by sustained negativity in oesophageal pressure or by prolonged flow limitation in nasal pressure transducer (Hernandez et al., 2001; Bao and Guilleminault, 2004; Johnson et al., 2005). As the oesophageal pressure monitoring is often considered unpleasant and the nasal pressure signal may be influenced by anatomic characteristics (Lorino et al., 2000), the detection of sustained partial obstruction with a sleep mattress seems feasible. Previously we have demonstrated that the sustained partial obstruction detected with a mattress (IRR) is accompanied by a sustained negative increase in oesophageal pressure and with flow limitation but not with apneas/hypopneas or desaturations (Tenhunen et al., 2011). During IRR the SDNN or LF power did not increase as during POB. Instead HF power increased and LF/HF-ratio decreased as compared to NB. These reflect an increase in vagal, parasympathetic activity, and decrease in sympathetic activity. From the pathophysiological point of view, the effects of the increase in intrathoracic negativity are supposed to induce similar processes both during POB and IRR. But as IRR does not comprise of arousals or transient desaturations, the sympathetic activation induced either by arousals or desaturations only, or by the additive increase caused by hypoxia associated with arousals is not present. Secondly, the prevailing lung inflation against resistance during IRR is capable of activating pulmonary stretch receptors, which increases vagal and reduces sympathetic output (Seals et al., 1993). The cumulative increase in transcutaneous carbon dioxide tension found in IRR (Rauhala et al., 2007) might also have an impact on vasomotor activity. An interesting finding is that despite the increased parasympathetic activity during IRR, the heart rate variability did not increase, as one might expect due to the increased vagal input to SA node. One reason for that might be that during IRR the breathing is remarkable regular and it could be even regarded as "controlled respiration" capable in shifting the sympathovagal balance towards the parasympathetic dominance (see Malliani et al., 1991). Whether our finding, that during IRR the heart rate variability did not increase along with the increasing HF power, is due to the increased tonic vagal outflow, which is no more capable to induce transient increases responsible for sinus arrhythmia (Malik and Camm, 1993) remains unsolved. However, it is evident that the impact of this increased nocturnal parasympathetic activity on cardiovascular health needs further emphasis.

One could argue that as IRR does not result in an increase in sympathetic tone it might even be favourable. This is partly supported by the finding that women with IRR have less hypertension than the general population (Anttalainen et al., 2010). But IRR might also induce harmful local processes on vasculature. Vibration, as snoring, may induce endothelial dysfunction which plays a pivotal role in the pathogenesis of atherosclerosis. IRR coincides usually with heavy snoring which has been associated with carotid atherosclerosis in humans (Lee et al., 2008). As the effect of IRR on autonomous nervous activity differs from the effects of sleep apnea, the co-morbidities can also be different. Or it might be that IRR of some degree would decrease the risk of cardiovascular diseases, but another degree of difficulty would be harmful. These aspects have to be further examined.

The use of HRV-analysis, which is strongly affected by sleep stage and the dynamics of respiration, can be discounted in the evaluation of SDB (Penzel et al., 2002). However, as HRV analysis has been applied to various SDB:s, as OSA, snoring, nocturnal alveolar hypoventilation and upper airway resistance syndrome (UARS) (Gates et al., 2005; Guilleminault et al., 2005; Kufoy et al., 2012; Palma et al., 2013), we feel that the evaluation of IRR would also be informative. IRR is usually combined with heavy or crescendo snoring and it comprises a quite similar increase in upper airway resistance as the UARS. However, the conventional UARS episodes are formed of repetitive, short flow limitation events accompanied by periodic oesophageal swings and terminated by arousals (Poyares et al., 2002; Guilleminault et al., 2005). Instead IRR episodes are longer, they are often associated with sustained, stable flow limitation and sustained increased negative oesophageal pressure values without repetitive arousals. Guilleminault et al. (2005) have presented that HR increase after UARS event was lower than after obstructive apnea but we did not observe HR differences between the breathing categories. This might result from the different methods; our analyses were focusing on long-term HRV characteristics of the SDB patterns rather than HRV changes around single events. In that way the results might not be comparable. However, the above mentioned papers suggest that the partial obstruction with preserved lung inflation could induce an increase in the parasympathetic activity. Whether this might account for the somewhat different subjective symptoms between the patients with OSAS, UARS and IRR, remains unsolved (Gold et al., 2003; Tenhunen et al., 2013).

To conclude, our HRV-results suggest that POB can be considered as a counterpart of OSA. This strengthens our view that the detection of periodic SDB constituting of apneas and hypopneas, is quite reliable with mattress sensors (Tenhunen et al., 2013; Vayrynen et al., 2014). The present study also suggests that prolonged partial obstruction can be considered as a different SDB entity and adds to our knowledge about IRR and its possible pathophysiological mechanisms. However, its impact on cardiovascular health still needs further evaluation.

Acknowledgements

The study was financially supported by Tekes, the National Technology Agency of Finland and by the Competitive Research Financing of the Expert Responsibility area of Tampere University Hospital, Grant Numbers 9M014 and 9P013.

Conflict of interest: None of the authors have a financial relationship with Emfit Ltd, Finland; the company that developed and sells the Emfit sensors or other conflicts of interests.

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